United States
Department of
Agriculture

Forest Service

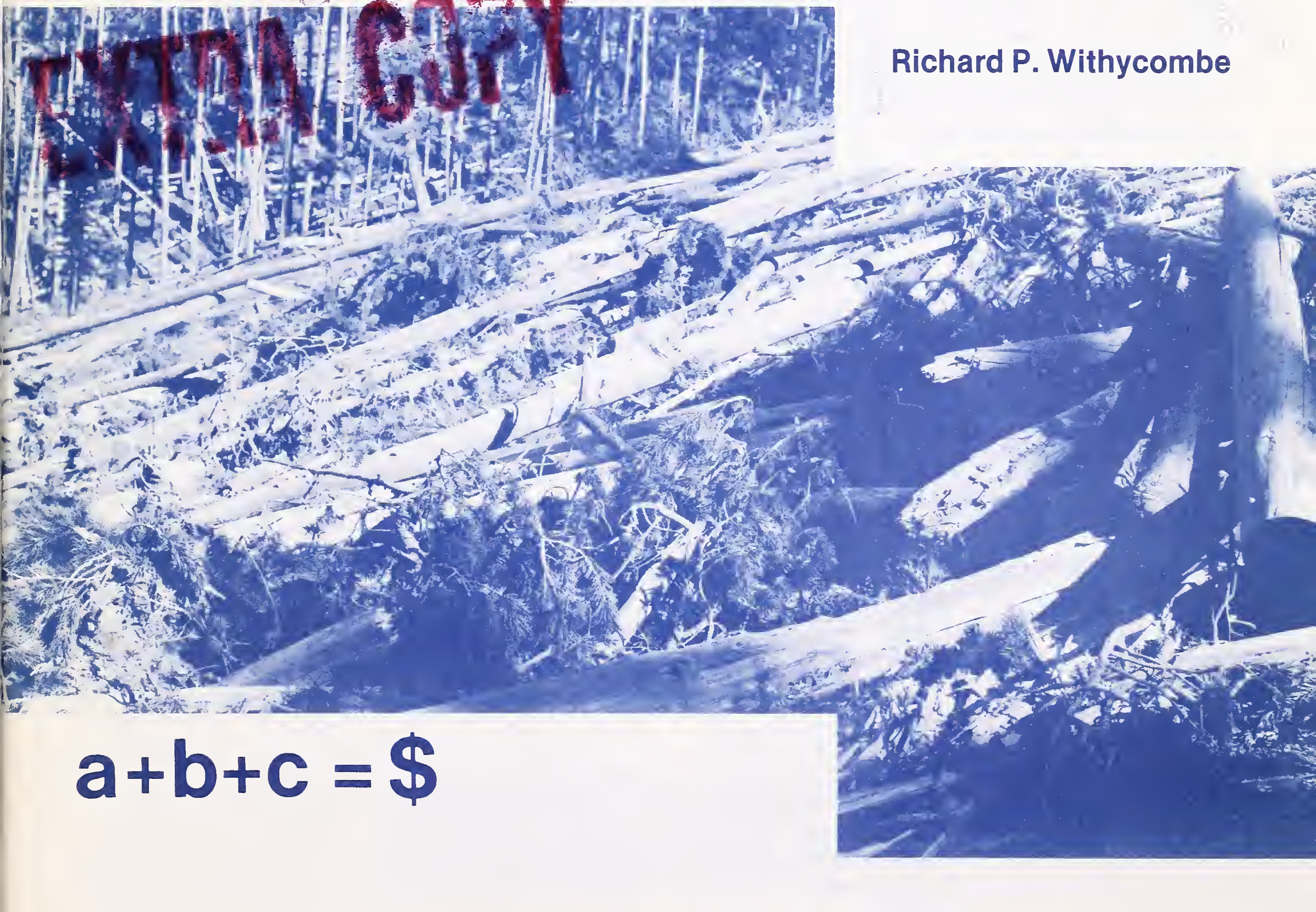
**Intermountain
Forest and Range
Experiment Station**
Ogden, Utah
84401

General Technical
Report INT-81

February 1982

Estimating Costs of Collecting and Transporting Forest Residues in the Northern Rocky Mountain Region

Richard P. Withycombe



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THE AUTHOR

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RESEARCH SUMMARY

Forest residues remaining after harvest are often technically suited for some fiber or solid wood product, but often the costs of removing these materials are judged to be greater than their value. Removal costs can be highly variable and little cost information is available that can be applied to residues.

A model is presented that determines cost per unit of harvesting wood residues. In deriving these costs such independent variables as skidding distance, volume per turn, and piece size are considered. Harvesting methods in the model include hand or mechanical felling, cable or ground skidding, chipping in woods, or roundwood logging.

Conversion factors and cost deflation factors are provided and, along with the independent variables, enable computation of residue harvest costs for a specific situation. Cost data are presented in a series of tables from which total costs can be summed.

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INTRODUCTION

During the past decade there has been a growing concern among forest managers and the public about what to do with the large amounts of unused wood in our forests. These forest residues consist of the wood fiber remaining after removal of the material that will make a commercial product, as well as material that will be left when unlogged sites are harvested. On land that has been logged, forest residues are tree limbs, tree tops, broken trunks, cull logs, undersize trees, and stumps. On unharvested land, forest residues are mostly standing dead, down dead, and dying trees, suppressed trees and unusable species. Most of the material is sound wood, so the constantly recurring question is: Why are these materials not being used to help satisfy the world's growing demand for wood?

The reasons they are not being used are mostly economic. Forest residues are not utilized because collection and transportation costs are judged to be greater than the value of the materials. As a general rule, we can assume that the logging and forest industries will take any material that will return a profit and will leave any that does not. This general rule may be modified by such factors as pricing policies that charge for marginal materials or contracts that require removal of all material.

The difference between the value of forest residues and the cost of collecting them can be extremely variable. Small-volume widely scattered residues in remote areas are expensive to collect, but the cost of collecting concentrated residues near the point of end use may be so small that a slight increase in the market value of the residue would make utilization profitable.

When decisions are to be made concerning the possible use of forest residues, it is important that estimates of the material collection and transportation costs be available. The residue collection cost tables presented here are estimates of the costs for collecting and transporting the types of forest residues common to the Northern Rocky Mountain region. The tables were developed from average costs over a broad range of variable conditions, and should be used only for purposes of estimation. For ease of use in estimating costs, tables 1 through 12 are grouped together in the section entitled "Residue Collection Cost Tables."

METHOD OF STUDY

Nearly all data used to construct the residue cost tables are from published sources. During the past 10 to 15 years, a great deal of information has been collected and published about the costs of logging. Many of the operations required in the harvesting of residues are the same as those in conventional logging; so logging costs can be used to simulate residue costs. The primary difference between the two is in distribution of piece size, with residues tending to be both smaller and more variable. The units of measurements are also different; logs are measured in board feet or occasionally in cubic feet, and residues are measured by cubic volume or by weight.

The data sources can be categorized into three groups: (a) timber appraisal data, developed by the two major public landholders, the Forest Service and the Bureau of Land Management; (b) special studies of logging equipment or systems usually published as monographs; and (c) case histories of specific operations reported in the various trade journals.

When available, the time required for each operation in the harvesting process was obtained. Time estimates from the various sources were converted as necessary to common units of measurements and then combined into a single time estimate. Methods used for combining the data from various sources were variable and were based primarily on judgment. Operation costs were obtained from the same sources and combined in the same manner as the time estimates after first being converted to a common time base of 1978 prices. The seven tables that comprise the cost model have been simplified by using average values for many of the variables affecting cost, but some variables have such a great effect on cost that average values could not be used. Such site-specific information as piece size and skidding distance is required.

USE OF THE COST MODEL

To determine which tables are to be used, the source and type of residue must be identified. Most of the residue in the Northern Rocky Mountain region can be classified either as logging residues or as standing dead trees. In the Northern Rockies, which include most of western Montana and northern Idaho, the majority of the residues are a direct result of logging operations. To the south, in southern Idaho and western Wyoming, the predominant residues are standing dead pines, the result of mountain pine bark beetle epidemics.

Figure 1 shows the sequence of cost table use for each of the two major residue types. One must determine residue type, ground slope, and availability of adequate landings to choose the correct tables.

The choice between hand felling and mechanical felling of standing dead trees is determined by both the slope and the total volumes of residues to be harvested. Mechanical fellers are generally not cost effective at slopes above 15 percent, so hand felling should be assumed on slopes above 15 percent. Even on flat ground, mechanical fellers are economical only if the volumes to be harvested are large enough to utilize the full capacity of the fellers over an extended period. One mechanical feller can produce about 10,000 cunits (28 300 m^3) per year, and mechanical felling should be assumed only if the total annual harvest of dead residues will be enough to use at least 75 percent of the feller's capacity. Hand felling costs are shown in table 1, and mechanical felling costs in table 2.

The choice between ground skidding or cable yarding is dependent on the slope of the ground. For sites with an average slope of 30 percent or less and a maximum slope of 40 percent, ground skidding (table 3) should be used. If the average slopes are greater than 30 percent, then cable yarding (table 4) is needed. For logging residues, the method used for commercial logging can be assumed to be the correct choice.

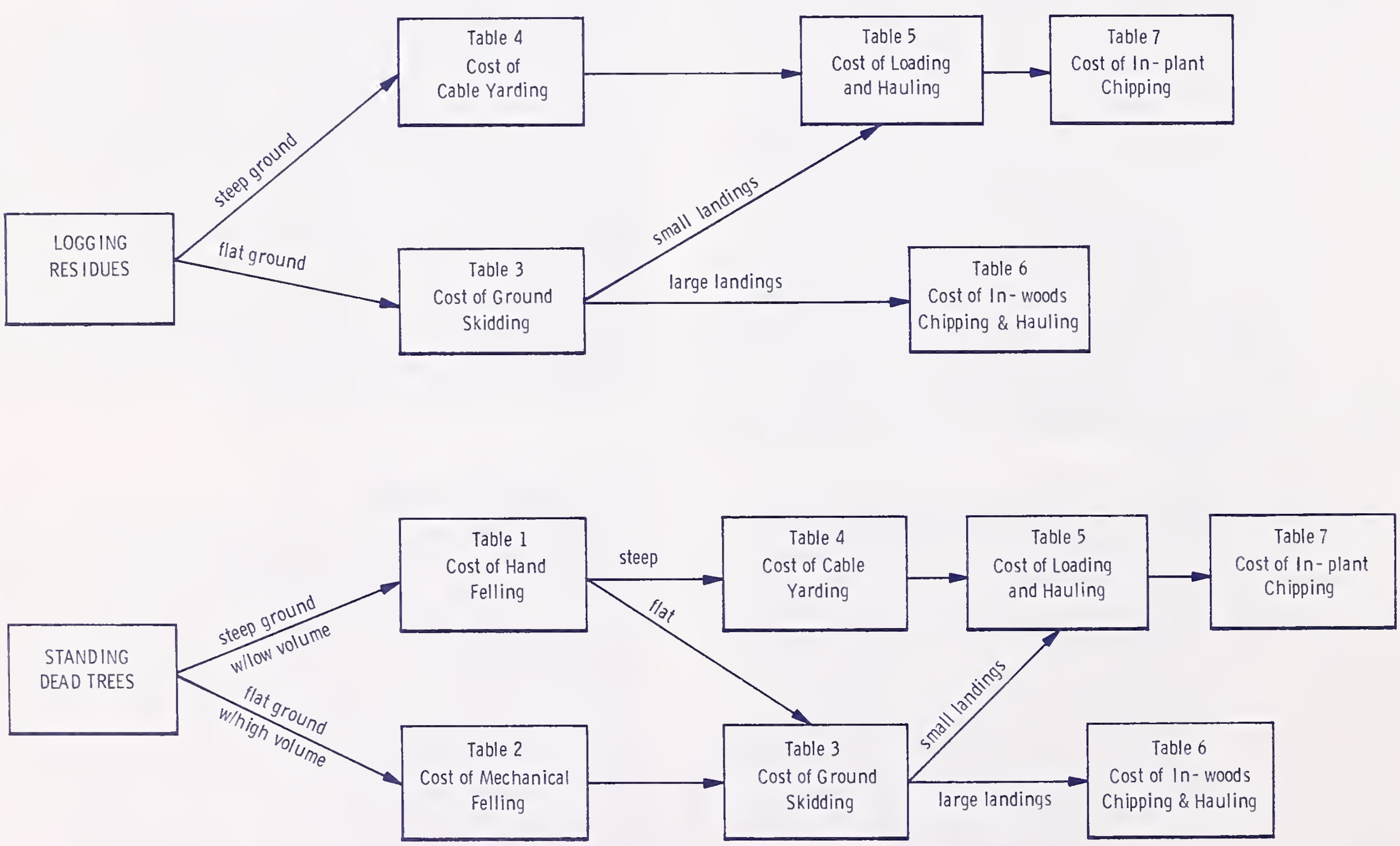

Figure 1.—Table selection guide for estimating costs of collecting logging residues or standing dead timber.

The third choice in the table selection is whether the material is to be chipped in the woods or to be hauled as pieces and chipped at a central plant. The choice is arbitrary to some degree, depending only on the preference of the end user. Small pieces tend to make in-woods chipping more economical and large pieces may necessitate in-plant chipping. The primary consideration will be the availability of adequate landing space. Effective utilization of in-woods chipping machinery requires large landings with a flat landing of about 75 ft by 150 ft being best. If the landing space is not adequate, the chipping costs may be several times those shown in the cost table. Since large landings are not common in the mountains of Montana and northern Idaho, estimates for these regions should assume that the chipping will be done in plant.

DATA REQUIREMENTS FOR USE OF THE COST TABLES

Piece Size

The costs of ground yarding, cable yarding, log loading, and log hauling are heavily influenced by the size of the residue material. The costs are much greater for smaller pieces, but the relationship between costs and size is not linear. Figure 2 shows the cost per cunit (see table 11 for definition) for ground skidding a distance of 300 ft (91 m). The cost rises sharply with decreasing piece size, so that costs based on average piece size would be understated. The example below shows the skidding cost properly weighted for piece size.

Residue	Piece size		Cost to skid 300 ft	
Percent	*Ft³*	*m³*	*\$/cunit*	*\$/m³*
30	2	0.06	36.80	12.99
50	10	.28	7.40	2.61
20	50	1.41	4.90	1.73
Weighted average	15.6	.44	15.72	5.55

If the skidding cost for each size piece is separately read from table 3 and averaged using the piece-size percentages as weights, the expected average cost is \$15.72 per cunit. If the size is first averaged using the same weights, and the resulting average piece size of 15.6 ft³ (0.44 m³) is used to determine the average cost, then the apparent cost is only \$4.90/cunit (\$1.73/m³) since the cost is constant above 15 ft³ (0.42 m³) per piece.

Because of the nonlinear relationships, average piece size should be used only if the residues are quite uniform in size. Lodgepole pine killed by *Dendroctonus ponderosae* Hopkins (mountain pine beetle) is often surprisingly uniform over large areas; so use of an average size may be justified. Logging residues, however, usually contain a wide variety of sizes. The various sizes should be grouped into three or four categories and the costs of yarding and loading determined separately for each by using the average size within each category to read the tables. The resulting costs can then be averaged as shown in the above example.

The piece size in the cost tables is expressed in cubic feet, while most data will be in terms of diameter and length. Table 10 can be used to convert from length and large end diameter (d.b.h. for full tree) to approximate cubic-foot volumes. The volumes shown include bark, which for the typical Rocky Mountain types will average about 15 percent of the total volume.

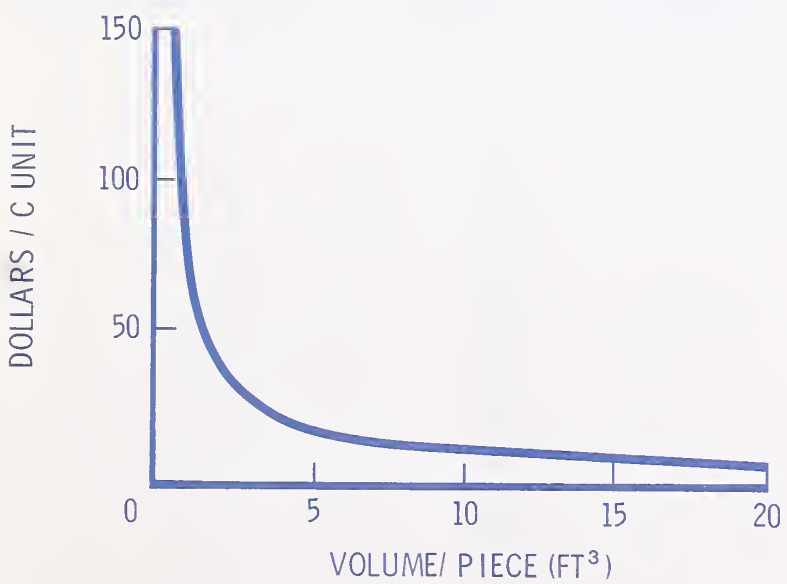

Figure 2.—The cost per cunit for ground skidding a one-way distance of 300 feet.

Diameter

The cost tables for both hand felling (table 1) and mechanical felling (table 2) require the diameter at breast height (d.b.h.). As with piece size, the relationship between cost and d.b.h. is not linear; it is a curve that rises sharply with decreasing diameter. If the residues to be felled show a wide variation in size, the resource should be separated into several size categories, with separate cost estimates for each, using the weighting techniques described for piece size. If the residues are relatively uniform, however, the use of an average diameter will cause no problems. Most of the residues in the Rocky Mountain region that will require felling are either pine killed by the mountain pine beetle or overstocked stands of suppressed timber, and both types are usually uniform in size.

Yarding Distance

The distance the material must be moved is a major factor in determining the ground-skidding cost. The relationship between the cost and the distance is linear; so average yarding distance can be used. The average yarding distance, calculated from the geometry of the site, is preferred, but a reasonable approximation can be obtained for many sites by figuring the average yarding distance as two-thirds of the maximum distance (U.S. Department of the Interior, Bureau of Land Management [BLM] 1977). If actual yarding distances are not available, the reported average yarding distance of 600 ft for western Montana can be used (USDA Forest Service 1978).

The yarding distance also affects the cost of cable yarding, but because the cost differences are rather small, they have been omitted from table 4 to reduce the size of the table. The costs shown in table 4 apply to short or moderate yarding distance (1,000 ft or 305 m maximum). For distances of 1,000 to 2,000 ft (305 to 610 m), the costs shown in table 4 should be increased by 20 percent. The table should not be used for distances over 2,000 ft (610 m).

Haul Distance

The cost tables for loading and hauling (table 5) and chipping and hauling (table 6) require the one-way haul distance between the harvest site and the point of use. The tables were based on the assumption that 10 percent of the distance will be on dirt roads, 20 percent on gravel roads, and 70 percent on paved roads. It is assumed that a portion of the haul will be on public roads that have load weight limitations. If local conditions vary greatly from the assumptions, an adjustment of the tabled values may be necessary. The adjustments are detailed in the section entitled "Notes on the Construction, Use, and Limitations of the Residue Collection Cost Tables."

EXAMPLES OF THE MODEL'S APPLICATION

Example A: High volume harvest of dead lodgepole pine.

For this example, it is assumed that the site is on relatively flat ground with large landings available. The material is relatively uniform in size, with an average d.b.h. of 10 inches (25.4 cm). The average skid distance is 400 ft (122 m) and the haul distance, 40 miles (64 km). The material is to be chipped in the woods without barking.

The average volume per piece obtained from table 10 is 16.3 ft³ (0.46 m³).

The appropriate cost tables are selected by reference to figure 1. The tables used and the cost per cunit are:

	Per cunit	Per m³
Table 2, mechanical felling, without limbing	$ 5.90	$ 2.08
Table 3, ground skidding	5.20	1.84
Table 6, in-woods chip and haul, not barked	18.54	6.54
Total cost	$29.64	$10.46

Example B: Low volume dead lodgepole on moderate slopes.

For this example, assume that the harvest site has slopes above 15 degrees, but less than 30 degrees. Adequate landings are available, so in-woods chipping is feasible. The trees are to barked before chipping, so the felling must include limbing. Ground skidding an average of 800 ft (244 m) is assumed. The material has a uniform 14-inch (36-cm) diameter and the haul distance is 20 miles (32 km).

From table 10, the volume per piece is 40 ft³ (1.13 m³). From figure 1, the relevant tables and the costs per cunit from each are:

	Per cunit	Per m³
Table 1, hand felling, with limbing	$ 5.30	$1.87
Table 3, ground skidding	6.30	2.22
Table 6, in-woods chip and haul, barked	15.98	5.64
Total cost	$27.58	$9.74

Example C: Logging residues on steep ground.

For this example, assume that the logging residues have the following size distribution:

(a) 3- to 5-inch (8- to 13-cm) diameter, 8-ft (2.4-m) long, 20 percent of total
(b) 6- to 10-inch (15- to 25-cm) diameter, 16-ft (4.9-m) long, 50 percent of total
(c) 14- to 22-inch (36- to 56-cm) diameter, 24-ft (7.3-m) long, 30 percent of total

The material is all on ground with slopes of 30 percent or greater, located within 500 ft (152 m) of a logging road. The landings are small so in-woods chipping is not feasible. The one-way haul distance is 60 miles (96 km). The material is to be chipped for fuel; so barking is not required.

By using the average diameter for each size class, table 10 can be used to convert the size distribution to cubic feet.

(a)	0.5 ft³ (0.014 m³)	20 percent
(b)	4.4 ft³ (0.12 m³)	50 percent
(c)	35.9 ft³ (1.0 m³)	30 percent

Referring to figure 1, the relevant cost tables are:

Table 4, cable yarding
Table 5, loading and hauling
Table 7, in-plant chipping

Each of the three size categories is costed separately. (Note: The tables are read to the closest value, without interpolation.)

	Table 4	Table 5	Table 7	Total	Percent
	$Cunit				
(a) 0.5 ft³	769.00	34.55	6.25	809.80	20
(b) 4.4 ft³	101.00	19.01	6.25	126.26	50
(c) 35.9 ft³	17.2	14.20	6.25	37.65	30

Average cost weighted by percent $236.39/cunit ($83.45 m³)

This example illustrates one of the problems inherent in estimating average costs for all residues in an area. Had a decision been made to leave the small material and to remove only the material in the two larger size categories, the total volume would be reduced by only 20 percent, but the weighted average cost would be reduced to $93.03 per cunit ($32.82/m³), a reduction of 60 percent.

RESIDUE COLLECTION COST TABLES

Tables that can be used to develop cost estimates for recovering forest residues are grouped in this section to facilitate use.

Table 1.—Cost of hand felling

D.b.h.		Felling only	Limbing only	Fell and limb
Inches	*cm*		[1] *$/Cunit*	
4	10	37.20	57.10	94.30
6	15	15.30	23.90	39.20
8	20	8.00	9.60	17.60
10	25	4.00	6.30	10.30
12	30	2.70	4.20	6.90
14	36	2.10	3.20	5.30
16	41	1.70	2.60	4.30
18	46	1.40	2.20	3.60
20	51	1.20	1.90	3.10
24	61	.90	1.50	2.40
28	71	.80	1.20	2.00

[1]To obtain $\$/m^3$, multiply tabled entries by 0.353.

Table 2.—Cost of mechanical felling

D.b.h.		Fell only	Fell and limb
Inches	*cm*	[1] *$/Cunit*	
4	10	69.00	81.80
6	15	26.80	31.80
8	20	11.10	13.20
10	25	5.90	7.00
12	30	3.50	4.20
14	36	2.40	2.90
16	41	1.70	2.10
18	46	1.30	1.50
20	51	1.00	1.20

[1]To obtain $\$/m^3$, multiply tabled entries by 0.353.

Table 3.—Cost of ground skidding

Volume per piece		Volume per load[1]		One-way skidding distance											
				Feet											
				50	100	150	200	300	400	500	600	800	1,000	2,000	3,000
				Meters											
				15	30	46	61	91	122	152	183	244	305	610	914
Ft^3	*m^3*	*Ft^3*	*m^3*	[2]*$/Cunit*											
0.5	0.01	5	0.1	125.6	130.0	134.2	138.4	147.0	155.6	164.2	172.8	190.0	207.2	293.2	379.2
1.0	.03	10	.3	62.8	65.0	57.1	69.2	73.5	77.8	82.1	86.4	95.0	103.6	146.6	189.6
1.5	.04	15	.4	41.9	43.3	44.7	46.1	49.0	51.9	54.7	57.6	63.3	69.1	97.7	126.4
2.0	.06	20	.6	31.4	32.5	33.6	34.6	36.8	38.9	41.1	43.2	47.5	51.8	73.3	94.8
3.0	.08	30	.8	20.9	21.7	22.4	23.1	24.5	25.9	27.4	28.8	31.7	34.5	48.9	63.2
4.0	.11	40	1.1	15.7	16.3	16.8	17.3	18.4	19.5	20.5	21.6	23.8	25.9	36.7	47.4
5.0	.14	50	1.4	12.6	13.0	13.4	13.8	14.7	15.6	16.4	17.3	19.0	20.7	29.3	37.9
10.0	.28	100	2.8	6.3	6.5	6.7	6.9	7.4	7.8	8.2	8.6	9.5	10.4	14.7	19.0
15.0 or over	.42	150	4.2	4.2	4.3	4.5	4.6	4.9	5.2	5.5	5.8	6.3	6.9	9.8	12.6

[1]Volume per load assumes ten pieces per load to maximum load of 150 ft^3.
[2]To obtain $\$/m^3$, multiply the tabled entries by 0.353.

Table 4.—Cost of cable yarding[1]

Average piece size		Yarding cost	
Ft^3	*m^3*	*$/Cunit*	*$\$/m^3$*
0.5	0.01	769	272
1.0	.03	390	138
1.5	.04	261	92
2.0	.06	197	70
3.0	.08	133	47
4.0	.11	101	36
5.0	.14	82	29
10.0	.28	43.2	15.2
15.0	.42	30.8	10.9
20.0	.57	24.8	8.8
25.0	.71	21.3	7.5
30.0	.85	19.3	6.8
40.0	1.13	17.2	6.1
50.0	1.42	16.0	5.6
60.0	1.70	14.0	4.9
70.0	1.98	12.4	4.4
80.0	2.26	11.1	3.9
90.0	2.55	10.1	3.6
100.0	2.83	9.3	3.3

[1]For yarding distances of 1,000 to no more than 2,000 ft, increase the costs shown by 20 percent.

Table 5.—Cost of loading and hauling

Average volume per piece		One-way haul distance												
		Miles												
		5	10	15	20	25	30	40	50	60	70	80	90	100
		km												
		8	16	24	32	40	48	64	80	97	113	129	145	161
Ft³	*m³*	*[1]$/Cunit*												
0.5	0.01	20.7	22.1	23.3	24.2	25.7	27.0	29.6	32.2	34.6	36.8	39.1	41.2	43.2
1.0	.03	17.6	18.6	19.6	20.6	21.8	22.9	25.2	27.5	29.6	31.6	33.5	35.4	37.2
1.5	.04	15.1	15.9	16.8	17.7	18.8	19.8	21.8	23.9	25.7	27.6	29.3	31.0	32.6
2.0	.06	13.2	14.0	14.8	15.6	16.5	17.5	19.3	21.2	22.8	24.5	26.1	27.6	29.0
3.0	.08	11.7	12.4	13.2	13.9	14.8	15.7	17.4	19.1	20.7	22.2	23.7	25.1	26.5
4.0	.11	10.6	11.2	12.0	12.7	13.5	14.3	15.9	17.5	19.0	20.4	21.8	23.1	24.4
5.0	.14	9.9	10.6	11.3	11.9	12.7	13.5	15.1	16.6	18.0	19.4	20.7	22.0	23.2
10.0	.28	8.4	9.0	9.7	10.4	11.1	11.9	13.4	14.8	16.2	17.5	18.8	20.0	21.2
15.0	.42	7.8	8.4	9.1	9.8	10.5	11.3	12.8	14.2	15.6	16.9	18.2	19.4	20.6
20.0	.57	7.5	8.1	8.7	9.4	10.1	10.9	12.4	13.9	15.2	16.6	17.8	19.0	20.2
25.0	.71	7.1	7.7	8.4	9.0	9.8	10.6	12.0	13.5	14.9	16.2	17.5	18.7	19.9
30.0	.85	6.8	7.4	8.1	8.7	9.5	10.2	11.7	13.2	14.6	15.9	17.2	18.4	19.6
40.0	1.13	6.4	7.0	7.7	8.3	9.1	9.9	11.4	12.8	14.2	15.5	16.8	18.0	19.2
50.0	1.42	6.1	6.7	7.4	8.0	8.8	9.6	11.1	12.5	13.9	15.2	16.5	17.7	18.9
60.0	1.70	5.9	6.5	7.2	7.8	8.6	9.4	10.8	12.3	13.7	15.0	16.3	17.5	18.7
70.0	1.98	5.8	6.4	7.0	7.7	8.4	9.2	10.7	12.2	13.5	14.8	16.1	17.3	18.5
80.0	2.26	5.6	6.2	6.9	7.5	8.3	9.0	10.5	12.0	13.4	14.7	16.0	17.2	18.4
90.0	2.55	5.4	6.0	6.7	7.4	8.1	8.9	10.4	11.9	13.2	14.6	15.8	17.0	18.2
100.0	2.83	5.3	5.9	6.6	7.2	8.0	8.8	10.2	11.7	13.1	14.4	15.7	16.9	18.1

[1]To obtain $/m³, multiply tabled entries by 0.353.

Table 6.—Cost of in-woods chipping[1] and hauling

One-way haul distance		Barked chips[2]	Not barked chips[2]
Miles	*km*	*[3]$/Cunit*	
5	8	13.18	11.37
10	16	14.05	12.24
15	24	15.04	13.23
20	32	15.98	14.17
25	40	17.09	15.28
30	48	18.19	16.38
40	64	20.35	18.54
50	80	22.51	20.70
60	97	24.49	22.68
70	113	26.41	24.60
80	129	28.28	26.47
90	145	30.03	28.22
100	161	31.78	29.97

[1]Chipping only costs are: barked, $9.04/cunit; not barked, $7.23/cunit.
[2]If the residues are to be barked prior to chipping, table 1 or 2 (if used) must provide for limbing. If the residues are not to be barked, and thus contain bark in the chips, limbing is not required.
[3]To obtain $/m³, multiply tabled entries by 0.353.

Table 7.—Cost of in-plant chipping

	$/Cunit	$/m³
Chip only[1]	6.25	2.20
Handling costs[2]	6.25	2.20
Total	12.50	4.40

[1]Chip-only costs include chipper, labor, power, and limited-yard handling.
[2]Handling costs include barking, bark and chip handling and storage, and screening of chips.

Table 8.—Cost of loading

Average volume per piece		Weight of full load		Loading cost	
Ft³	*m³*	*1,000 pounds*	*1,000 kg*	*$/Cunit*	*$/m³*
0.5	0.01	30	14	16.1	5.7
1.0	.03	34	15	13.3	4.7
1.5	.04	38	17	11.2	4.0
2.0	.06	42	19	9.7	3.4
3.0	.08	45	20	8.4	3.0
4.0	.11	48	22	7.5	2.6
5.0	.14	50	23	7.0	2.5
10.0	.28	52	24	5.6	2.0
15.0	.42	52	24	5.0	1.8
20.0	.57	52	24	4.6	1.6
25.0	.71	52	24	4.2	1.5
30.0	.85	52	24	3.9	1.4
40.0	1.13	52	24	3.6	1.3
50.0	1.42	52	24	3.3	1.2
60.0	1.70	52	24	3.1	1.1
70.0	1.98	52	24	2.9	1.0
80.0	2.26	52	24	2.8	1.0
90.0	2.55	52	24	2.6	.9
100.0	2.83	52	24	2.5	.9

Table 9.—Cost of hauling

One-way distance		Assumed values: Dirt road		Assumed values: Gravel road		Round-trip time	Cost per trip
Miles	*km*	*Miles*	*km*	*Miles*	*km*	*Minutes*	*Dollars*
5	8	2	3	2	3	71	29.6
10	16	2	3	2	3	86	35.9
15	24	2	3	3	3	103	43.0
20	32	2	3	4	5	119	49.6
25	40	2.5	4	5	6	138	57.6
30	48	3	5	6	8	157	65.5
35	56	3.5	6	7	10	175	73.0
40	64	4	6	8	11	194	80.9
45	72	4.5	7	9	13	212	88.4
50	80	5	8	10	14	231	96.3
55	89	5	8	11	16	248	103.4
60	97	5	8	12	18	265	110.5
65	105	5	8	13	19	281	117.2
70	113	5	8	14	21	298	124.3
75	121	5	8	15	23	315	131.4
80	129	5	8	15	24	330	137.6
85	137	5	8	15	24	345	143.9
90	145	5	8	15	24	360	150.1
95	153	5	8	15	24	375	156.4
100	161	5	8	15	24	390	162.6

Table 10.—Volumes[1] of selected stems and stem segments in typical Northern Rocky Mountain stands; cubic feet, including bark[2]

Large end diameter or d.b.h.		Tree segment length: 8 ft (2.4 m)	16 ft (4.9 m)	24 ft (7.3 m)	32 ft (9.8 m)	Full tree
Inches	*cm*	*[3]Cubic feet*				
4	10	0.5	0.9	1.1	1.4	1.4
6	15	1.3	2.3	2.9	3.5	3.6
8	20	2.5	4.4	5.8	7.0	8.7
10	25	3.9	7.2	9.8	11.9	16.3
12	30	5.8	10.6	14.7	18.2	27.4
14	36	8.0	14.8	20.7	25.8	40.0
16	41	10.5	19.7	27.8	34.9	55.8
18	46	13.4	25.3	35.9	45.4	75.1
20	51	16.6	31.6	45.1	57.2	98.2
24	61	24.1	46.2	66.6	85.2	157.0
28	71	33.0	63.7	92.2	118.8	235.2
32	81	43.3	83.9	122.0	158.0	335.0

[1]Volumes not listed may be calculated using Smalian's Rule. Table assumes taper of 1 inch per 8 feet.

$$V = 0.005454 \frac{L\ (D^2_S + D^2_l)}{2}$$

L = length in feet
D_S = small end diameter in inches
D_l = large end diameter in inches

[2]To obtain volume without bark, reduce the tabled values by 8 percent for lodgepole pine, or by 20 percent for other species.

[3]To obtain cubic meters, multiply tabled entries by 0.0283. For volumes not listed, Smalian's Rule may be used. Table assumes taper of 0.9 cm per meter of length.

$$V(m^3) = 0.00007854 \frac{L\ (D^2_S + D^2_l)}{2}$$

L = length in meters
D_S = small end diameter in centimeters
D_l = large end diameter in centimeters

Table 11.—Residue conversions

Unit	Conversion
Cunit	= 100 ft³ of solid wood[1] = 2.83 m³ of solid wood ≅ 5,000 lb green weight ≅ 2,500 lb ovendry weight
b.d.u. (bone dry unit)	= 2,400 lb ovendry wood[1]
Cord	= 128 ft³ of stacked wood[1] ≅ 85 ft³ of solid wood ≅ 2,125 lb ovendry weight
b.d.t. (bone dry ton)	= 2,000 lb ovendry wood[1] = o.d.t. (ovendry ton)[1]
Unit	= 200 ft³ of chipped material[1] ≅ 75 ft³ of solid wood ≅ 3,750 lb green weight ≅ 1,875 lb dry weight
M bd. ft. (thousand board feet)	≅ 2 cunits of solid wood

[1]Definition of the unit. All other conversions employ one or more assumed values.

Table 12.—Cost inflators/deflators used in the construction of the residue cost tables

Year	Wholesale price index[1]	Conversion factor to 1978 basis
1965	96.6	2.17
1966	99.8	2.10
1967	100.0	2.10
1968	102.5	2.05
1969	106.5	1.97
1970	110.4	1.90
1971	113.9	1.84
1972	119.1	1.76
1973	134.7	1.56
1974	160.1	1.31
1975	174.9	1.20
1976	183.0	1.15
1977	194.2	1.08
1978	210.6	1.00

[1]The wholesale price index shown is the wholesale price index for all commodities published in "Business Statistics" by the U.S. Department of Commerce.

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NOTES ON THE CONSTRUCTION, USE, AND LIMITATIONS OF THE RESIDUE COLLECTION COST TABLES

Table 1. Cost of Hand Felling

The time required to hand fell dead trees was derived primarily from data provided by Adams (1967) and the USDI (1977) and was verified by comparison to experienced costs collected by the National Forest Region 1 timber appraisal group (USDA 1978). In the size range of 8- to 10-inches (20- to 51-cm) d.b.h., the sources are in close agreement, and the costs in table 1 can be expected to have an overall accuracy of plus or minus 20 percent. Beyond this range, the variation is much greater, especially for the small sizes. The table can be extrapolated to obtain costs for sizes somewhat greater than shown, but it should not be extended to smaller sizes. The cost shown for a 4-inch (10-cm) d.b.h. may differ from actual costs by as much as 50 percent; the error increases rapidly at smaller diameters. The costs shown for limbing include the cost to make one bucking cut to overall length.

Table 2. Cost of Mechanical Felling

The Woodlands Research Division of the Pulp and Paper Research Institute of Canada (PPRIC) and its successor organization, the Forest Engineering Research Institute of Canada (FERIC), have conducted and published extensive studies of mechanical tree harvesting systems during the past decade. The costs in table 2 are a combination of the time and cost estimates from 12 of the PPRIC and FERIC publications (Cottell 1977; Folkema 1977; Folkema and Novak 1976; Heidersdorf 1974, 1976; Powell 1971a, 1973, 1974a, 1974b, 1974c, 1975; Powell and Myhrman 1977).

Although the time required for mechanical felling is dependent on a number of variables such as slope, tree spacing, and tree size, the total variation between different systems was much greater than could be explained by any of the variables. The average reported time of 0.70 minute per tree without limbing and 0.83 minute per tree with limbing was therefore used to construct table 2. The hourly cost of operating a mechanical feller is also quite variable, but the variation possible for a single machine is much greater than the differences between the various machines. The FERIC and PPRIC reports show calculated costs under both favorable and unfavorable costs, and the midpoint between the two was used for table 2. The unfavorable costs are typically double the favorable costs, and these possible large variations in operation cost coupled with the variability in the operating times mean that there may be large differences between actual costs and those shown in table 2. The variation may exceed 50 percent. Low operating costs can be expected only if the entire system has sufficient support capacity to keep the harvester working full time over an extended period.

Table 3. Ground Skidding Cost

A number of extensive studies of the time required for ground skidding have been made. Table 3 is based on time estimates obtained by combining the results of seven of them (Cottell, Winer, and Bartholomew 1971; Host and Schlieter 1978; Koger 1976; Legault and Powell 1975; McMorland 1977; Powell 1971b; Sampson and Donnelly 1977). The studies were combined by using average values for all variables except distance, which yielded a time estimate of $T = 14.1 + 0.01D$, where D is the one-way skid distance in feet and T is the round-trip time in minutes. The hourly cost of $25.80 for the skidder and operator is from USDI (1977). Table 3 was constructed by assuming that the load per skidder turn would be 10 pieces, but would not exceed 150 ft^3 (4.2 m^3). Under good conditions, a grapple skidder could haul more than 10 small pieces; so the values in table 3 should be adjusted for a greater volume if appropriate.

Table 4. Cable Yarding Cost

The time required for cable yarding is dependent primarily on the piece size, with yarding distance and the number of pieces per turn having a much smaller effect. For construction of table 4, all variable conditions except piece size have been held constant at average values. The number of pieces per shift is estimated as $N = (208 - 2V)$ for per-piece volumes of 0.4 to 50 ft^3 (0.01 to 1.4 m^3) (V equals volume per piece) and as $N = (133 - 0.5V)$ for per-piece volumes greater than 50 ft^3 (1.4 m^3). The cost per day for the equipment and a four man crew is estimated as $800. The costs in table 4 should be used only for a relatively short yarding distance (to 1,000 ft [305 m]). Above 1,000 ft, the yarding distance, which was omitted from the tables, has a considerable effect on the total time; consequently, the costs in table 4 will be too low. The tabled values should be increased by 20 percent for distances of more than 1,000 ft, and the table should not be used for yarding distances of more than 2,000 ft.

Most cable yarding machines have been designed to handle large logs and are very inefficient when used for small pieces. Although table 4 shows costs for the full range of sizes used in the other tables, the very high cost of cable yarding at average piece sizes of less than 15 or 20 ft^3 (0.4 or 0.6 m^3) precludes cable yarding as a reasonable alternative. In situations where steep slopes make ground skidding impossible, the high cost of cable yarding really means that the small residues are inaccessible to existing equipment. There is a trend toward the development of small cable yarding systems (Blackman 1977; Case and Sulter 1976) which will reduce the costs of yarding small pieces, but the cost reductions are unlikely to be enough to make cable yarding of small residues economically feasible.

Table 5. Loading and Hauling Cost

The costs of loading and of hauling logs or residue pieces have been combined in table 5. On-highway log trucks were assumed to have a maximum load of 52,000 pounds (23 553 kg), or 1,040 ft³ (29 m³). For smaller pieces, the assumed load was reduced because of the difficulty of loading many small pieces on a truck. At average piece sizes smaller than 10 cubic feet (which amounts to 104 logs per load), the load size was steadily reduced to a load of 30,000 pounds (13 590 kg) for pieces averaging only 0.5 ft³ (0.01 m³). The loading time varies from 50 minutes per load for large pieces, to 125 minutes for very small pieces. The combined cost of the truck and driver and the loader and operator is $46 per hour.

The round trip time and the hauling cost are dependent on both the total distance and the type of roads. For construction of table 5, it was assumed that dirt roads would comprise 10 percent of the total distance, with a minimum of 2 mi (3 km) and a maximum of 5 mi (8 km); gravel roads would comprise 20 percent of the total, with a minimum of 2 mi (3 km) and a maximum of 15 mi (24 km); and that paved roads would comprise the remainder. For significant departure from these assumptions, the cost per load should be modified by $1.30 for every mile of dirt road greater or less than the assumed value ($0.81 per km) and by $0.75 for every mile of gravel road ($0.40 per km). The average cost for the log truck and driver is $25 per hour whether operating or delayed.

Table 6. In-Woods Chipping and Hauling Cost

The cost of chipping residue material in the woods and then hauling the chipped material in vans to a central location is one of the few costs of residue handling that is not heavily influenced by piece size. Portable chippers do have maximum size limits, but they are available in sizes able to handle nearly all residue in the Rocky Mountain region. The production rate for in-woods chippers averages 8.3 cunits (23 m³) per hour regardless of the residue size and whether the material is barked or not. The cost of the equipment is, however, about $75 per hour with the barker and $60 without. This cost includes the chipper and operator and a front end loader with operator to help with material supply to the chipper and to spot empty vans.

The chips are assumed to be hauled in 10-cunit (50,000 pound) (28 m³ or 22 650 kg) capacity vans, which cost $35 per hour. The cost includes an extra van which is filled at the landing while the loaded van is being hauled to the mill. The round trip times are the same as for log trucks.

Large variations from the costs shown in table 6 are possible. Under very good conditions, the cost may be half that shown, whereas poor conditions might result in costs several times those shown in table 6. The requirements for effective chipping are a continuous supply of material to the chipper and an adequate landing to allow free movement of raw materials and the chip vans.

The chip vans may be unable to negotiate many of the logging roads that present no problem to log trucks, and they may not stand up to long hauls over rough roads. As a general rule, in-woods chipping should not be considered for mountainous country where the roads may have sharp switchbacks and where level landing space is at a premium.

Table 7. In-Plant Chipping Cost

The cost of chipping shown in table 6 includes the cost of a stationary chipper, with the necessary labor and power to produce chips from residues. It includes a limited amount of yard and chip handling, and chip storage. The cost of $6.25 per cunit ($2.20/m³) would be appropriate for residues that are to be used for fuel, or as a low grade filler in composite panels. If the chips are to be used for paper, an additional cost of $6.25 per cunit ($2.20 m³) is required for barking, bark and chip handling and storage, and screening of the finished chips.

Table 8. Loading Cost and Table 9. Hauling Cost

Tables 8 and 9 show the loading and hauling costs that were combined in table 5. There may be situations where adjustments to either the loading or the hauling costs are needed to account for local conditions, and these tables have been included to make such adjustments easier. For the assumptions used in constructing the tables, see the section on table 5.

Table 10. Volumes of Selected Trees or Tree Segments

The cubic foot volumes shown in table 10 were used in converting the data from the various sources to a common measurement of cubic feet. This table differs somewhat from the usual cubic foot table in that the measurements shown include bark and the diameter measurements are at the large end. The column headed "tree length" was derived from gross volume tables developed by Faurot (1977) by averaging the volumes for typical tree heights for the four common Rocky Mountain species: ponderosa pine, lodgepole pine, western larch, and Douglas-fir. To obtain volumes without bark, reduce the values in table 10 by 8 percent for lodgepole pine and by 20 percent for the others.

Table 11. Residue Conversions

Just as there are a number of scaling rules used for measuring logs, there are many ways to measure residues, and there will often be a need to convert from one system of measurement to another. Some of the measurement conversions follow directly from the definition of the units, but many of them depend on such things as the wood density or moisture content. The conversions shown in table 11 are based on assumed values for the types of residues likely to be found in the Northern Rockies and should not be used for other purposes.

Table 12. Cost Inflators/Deflators

The costs that are shown in tables 1 through 9 are based on published reports of studies conducted over the past decade. During that time, prices have changed dramatically; so a conversion of all cost data to a common time basis was required. There are many price indexes available for the purpose, but none of them are directly connected to the costs of forest harvesting. The Wholesale Price Index, which includes producer prices for all commodities, was selected as the index that would most closely approximate the cost of residue collection. All costs were converted to 1978 equivalents by first dividing the cost by the index for its year and then multiplying by the index for 1978.

It is suggested that any costs obtained from tables 1 through 9 be converted to the equivalent cost in the desired year. New values of the index are available from several sources, the most convenient probably being the "Survey of Current Business," which is published monthly by the U.S. Department of Commerce, Bureau of Economic Analysis. (The page and section number may vary, but one should look under Commodity Prices, subsection—Producer Prices.)

To convert the prices shown in the residue cost tables to a later year, divide the costs by 210.6 (the index for 1978) and multiply by the new price index.

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Withycombe, Richard P.
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A model is presented for computing the costs of harvesting forest residues, based on several key characteristics of the residues and the logging area. Costs per unit are presented in tabular form for several alternative harvesting methods.

KEYWORDS: harvesting, logging cost, forest residues, utilization, cost models

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

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